Refinement and Testing of the MI Navigation Algorithm

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http://www.onr.navy.mil/sci_tech/ocean/onrpgahb.htm
http://www.onr.navy.mil/sci_tech/ocean/info/VSWSZMCM/
http://www.onr.navy.mil/sci_tech/ocean/info/VSWSZMCM/BAKGRND.htm

LONG-TERM GOALS

Our long term goal is to establish the feasibility of using Very Low Frequency (VLF) Magnetic Induction (MI) as a practical technology for providing navigation information to divers or Autonomous Underwater Vehicles (AUVs) performing any of a variety of tasks in choppy salt water where RF and sonar methods are difficult to apply.

OBJECTIVES

The specific objective of this program is the development of an MI-based navigation technology for use by divers, swimmers or by small AUVs in a wide range of countermine and reconnaissance missions, conducted primarily in the surf zone or very shallow water. The approach will be platform independent, immune to surf noise and geographic variations, be clandestine in operation and provide an operating radius of at least a kilometer.

APPROACH

We are teamed with MI Systems Ltd. of Nova Scotia, who are tasked with the implementation of the hardware and firmware needed to implement the navigation system and to provide support in conceptual development and test and evaluation.

We at Foster-Miller are driving the overall development of the system and working on its integration into actual vehicles and potential missions.

WORK COMPLETED

This program is a continuation of N00014-97-C-0285 (VLF Magneto-Inductive Signaling and Navigation) reported last year. The contract was awarded 20 April 2000. Work has proceeded on two fronts:

- Definition of a Test Plan for further confirmation of the magnetic field theory basis for the navigation method and implementation of the hardware needed for conducting these tests.
- Theoretical exploration of improved approaches to the mathematical algorithm used to calculate position from the field measurements.

RESULTS

Hardware and Testing

The test plan has been written and is undergoing an internal review. The plan describes in detail the proposed test area and required site preparations, the test apparatus (beacons, receivers and data acquisition equipment) and testing procedures. Also discussed in the plan are issues surrounding equipment calibration, data analysis and final system assessment.

The stated objectives of the proposed tests are to:

- Determine the magnetic field vector in the navigation area produced by a dipole (beacon) deployed in a very shallow water area.
- Perform computations of position using various forms of the navigation algorithm with data from field measurements taken at known locations with respect to the beacons and to compare calculation with actual position.
- Establish an error range for the system using the above data indicating the precision to which the navigation system may be expected to perform.

Work continued on the hardware upgrades. The triaxial sensor is being built. All housing and mechanical features have been constructed. Work remaining involves the construction of a new triaxial antenna configuration designed for operating at very low frequencies (i.e. 35 Hz) along with improvements to the receiver board design.

The second navigation beacon is being built to the specifications of the existing beacon used in our previous navigation tests (July 1999). As shown in Figure 1, the two beacons are MI transmitter coils comprised of a solenoid winding over a magnetically permeable core. The beacons will measure approximately 42”x 10” and will each have a magnetic moment of 1200A-m^2.

Figure 1: Wound Cores for the Two Beacons being built for Upcoming Navigation Field Tests.

Algorithm Work

The Gashus Algorithm for tracking position with respect to a magnetic dipole beacon in three space has been extended. With the original algorithm, a receiver was initialized in a known orientation in X, Y and Z space with respect to the beacon and was then allowed to move with respect to it. The algorithm correctly determines the new series of locations using only the information from this one beacon. A compass and tilt sensor are used to correct for angular misalignment in this 3D approach. Robust performance was demonstrated in simulation, even in the presence of significant noise (error) on the received signals.

In the new implementation of the algorithm, two co-located beacons are used, one with horizontal axis and another with its axis vertical. We use six degrees of freedom – X, Y, Z and Roll (R), Pitch (P) and Yaw (W). (Yaw is equivalent to azimuth.) The receiver is again initialized, but with respect to all six degrees of freedom. The new algorithm determines subsequent values for location and orientation as the sensor is moved and rotated through six-space. No compass or tilt corrections of any kind are needed.

The new algorithm has been implemented in simulation and 10 to 15 runs have been conducted to date to get a feel for its performance. At small roll pitch and yaw angles (less than a radian (57 degrees)), the algorithm performs every bit as robustly as its 3D counterpart. When large angles are encountered, the spatial coordinates are still determined robustly, but ambiguities enter into the determination of the angles. Figure 2 illustrates the performance with the pitch and roll axis data. At first blush, it appears that there is serious confusion between actual position and that predicted by the algorithm. A little thought and analysis, however, clears this up.

In the first part of the run, predicted and actual angles track exactly. About 1/8 of the way through (first vertical line), in its random walk the pitch angle passes through $\pi/2$. This means that the platform's vertical axis is now horizontal. This is a major crossover point in the angular coordinate system. The algorithm reacts by finding a solution where the roll axis is offset by -7π (same as $-\pi$) and the pitch angle is measured in terms of $-\pi/2$ - P (where P is the originally defined pitch angle). In other words, the angular coordinate system has been shifted to an equally valid one, which is turned upside-down from the original.

As the actual pitch comes back through $-\pi/2$, the algorithm snaps back to the original coordinate system (second vertical line in the figure).

At the third vertical line, the pitch goes back through $-\pi/2$, the coordinates are flipped upside-down again and remain there through the rest of the run.

The remarkable feature of this behavior is that the positional coordinates are preserved by the angular transformation performed by the algorithm. At such large angles, their meaning is limited to being parameters in rotation matrices – their physical significance is not meaningful. At a pitch angle of $\pi/2$, the azimuth in the world system is measured about the vehicle's roll axis!

Work will continue in the coming months conducting further trial runs with the algorithm. We will probably limit angular excursion to ranges to be expected in operation with crawling platforms, but it should be recognized that the approach can easily be applied to highly mobile swimmers as well.

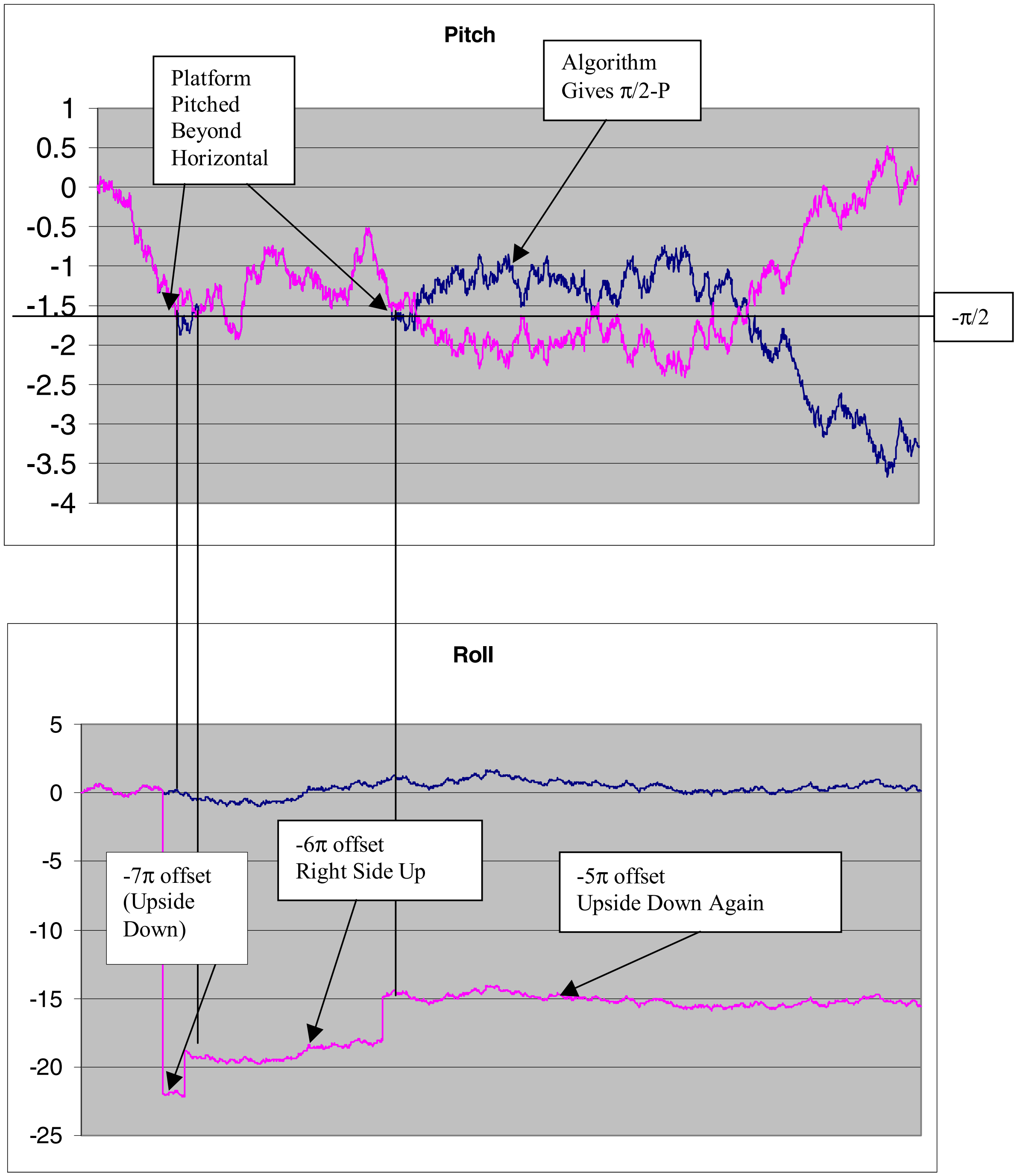

Figure 2: Behavior at Large Pitch and Roll Angles

IMPACT/APPLICATIONS

The development of a reliable and accurate means of navigation for use by small AUVs in very shallow water or the surf zone is of pivotal importance to the use of these vehicles in all of the missions for which they have been proposed. Two such missions would include general reconnaissance, where Side Scan or Synthetic Aperture Sonar equipped AUVs might be used to scout the underwater hydrography, or a more detailed search, in which the AUVs might be used to gain an assessment of the actual number and location of undersea mines. In both scenarios it is obvious that accurate positional information is needed both to make the data gathered useful to the user and to allow the registration of data sets collected by multiple vehicles.

There are few ways to accomplish the needed localization. Conductive seawater eliminates the use of any RF technique entirely. What remains is sonar and the low frequency magnetic induction technology being described here. Sonar is plagued in shallow water with a difficult multipath propagation problem, channel dropout caused by surf, and an inability to measure through intervening objects such as large rocks or abrupt dropoffs.

MI technology is decoupled from all of these problems. The one potential difficulty is distortion of the shape of the field due to magnetic anomalies or the finite thickness of the conducting water or even mixtures of fresh water in riverine areas. The measurements made during the Phase II work have shown that the distortions of the field due to seawater are insignificant in the navigation process.

The principal benefit of this program has been the detailed definition and demonstration in principle of the MI Navigation technology from which can be derived many variations for a broad range of missions.

TRANSITIONS

Work under this program has led to a proposal being submitted to ONR's VSW / SZ MCM BAA 98-008 for incorporation of the technology onto a working AUV for demonstration purposes. We anticipate continuation of the development effort in GFY 00.

RELATED PROJECTS

There is significant effort underway in the areas of development of AUV platforms and mission packages which will require navigation services, MI technology being a prime candidate. We are involved in two DARPA SBIR programs: One to investigate AUV platforms and the underwater instrumentation required for the general reconnaissance mission (Sea Snoop, DARPA SBIR 972-079), and the other to investigate to integration of Synthetic Aperture Sonar with a bottom crawling AUV, exploring whether motion compensation of the images is possible in this highly variable environment (SAS Snoop, DARPA SBIR 98-001).

REFERENCES

STTR N97T005 Phase I Report Dated 5 January 98, Foster-Miller Inc.

STTR N97T005 Phase I Final Report Dated 1 July 98, Foster-Miller Inc.

STTR N97T005 Phase II Final Report Dated 15 February 00, Foster-Miller Inc.